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Thermal Effects in Optical Devices

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Abstract

Whispering gallery mode optical resonators are of particular interest due to their applications in satellite communications, optical computing and biochemical detection. These resonators are ideal for such applications because of their high quality (Q) factors and small mode volumes. However, because of the small mode volumes, high intensity optical fields build up in these devices and cause them to undergo warming, leading to subsequent nonlinear thermal effects. Thermal broadening, one of the more common thermal effects experienced by these devices, leads to a broadened resonance peak. This effects reduces the accuracy of measurements during experiments and the reliability of the device's performance in applications. In this project, we are testing toroids in water and air, while altering parameters such as coupled power, scan rate and quality factor to determine a relationship between the full-width at half-maximum (FWHM) of the broadened peak and coupled power of the device to quantify thermal broadening.

Background

Optical resonators are devices that confine light waves through an arrangement of mirrors. A traveling wave resonator is a type of optical resonator that traps light through total internal reflection, allowing the light to propagate throughout the resonator. One such traveling wave resonator is the microtoroid, also known as a whispering gallery mode resonator (Fig 1), so named because it confines light in a closed circular loop in the same manner as a whispering gallery structure. St. Paul's Cathedral in London is a prime example: a whisper at one focus point can be heard clearly at another focus point in the dome (Fig 2).

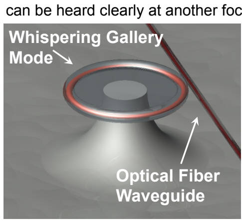


Fig 1

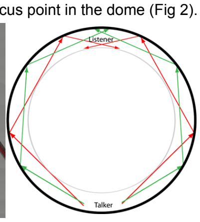


Fig 2

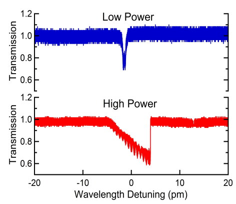
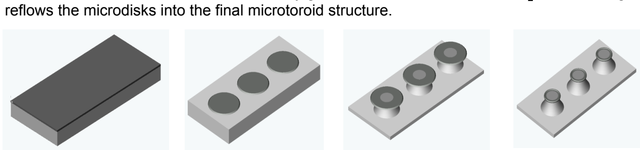


Fig 3

When the device is "on-resonance," light remains confined within the device until the pump wavelength is altered. All resonators have quality (Q) factors that measure the characteristic of the device to store energy, with higher Q indicating better energy storage. The Q factor can be measured when the device is "on-resonance" and includes the intrinsic Q of the device reduced by coupling loss, material loss, scattering loss, and other factors. In thermal broadening, the device experiences a resonance shift due to heating. As more power is coupled into the resonator, a high intensity circulating optical field heats the device and causes the resonance peak to shift. Therefore, instead of obtaining a sharp resonance peak, a broadened peak is observed instead (Fig 3). This is unfavorable because the resonant wavelength is a convenient way to characterize the resonator, since it is sensitive to any changes in or near the surface of the cavity. Thermal broadening alters our ability to measure the resonant wavelength, therefore affecting our ability to determine the true optical behavior of the device.

Device Fabrication

Through a series of photolithography, BOE etching, and XeF_2 etching steps, microdisks are fabricated from silicon wafers with thermally grown oxide on the surface. CO_2 laser heating reflows the microdisks into the final microtoroid structure.

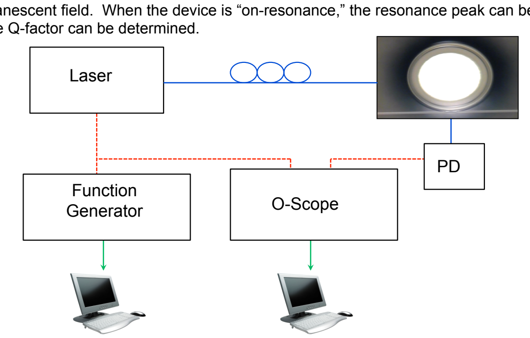


1. Sol-gel layers on Si substrate.
2. Circular pads etched onto substrate.
3. XeF_2 etching to form microdisks.
4. CO_2 laser reflow to form microtoroids.

D. Armani et al, *Nature* **421** (2003). X. Zhang, H. S. Choi, A. M. Armani, Appl Phys Lett. **96** 153304 (2010).

Testing Set-up

Using a tapered optical fiber connected to a laser source, light is coupled into the device through the evanescent field. When the device is "on-resonance," the resonance peak can be observed and the Q-factor can be determined.



Data Collection

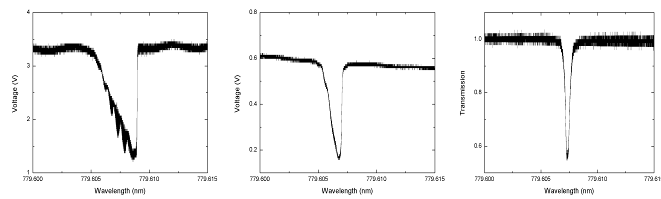
In order to characterize thermal broadening, the phenomenon was measured for microtoroids at different input powers. The sizes of the toroids varied from 60 to 100 um. The devices were tested in air and water, to observe the phenomenon in two different mediums. Multiple resonances were measured at different scan rates to determine if there were any relation to thermal broadening and the Q-factor of the device or the scan rate at which the resonance peak is measured.

Data Analysis

To analyze the data, I wrote a Matlab program that allows me to input the data file and extract the desired parameters. In this case, I chose to track the change in full-width at half-maximum (FWHM) of the thermally broadened resonance peak as the power coupled into the device was changed. The program requests the input power and data file for the resonance peak and calculates the FWHM of the broadened peak and the corresponding power coupled into the device.

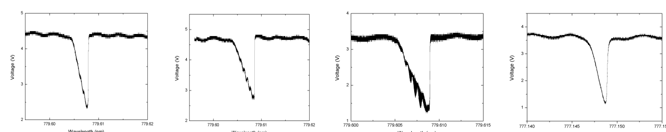
Results

The amount of power coupled into the device has a significant effect on the FWHM of the broadened peak. As shown below, as the input power decreases, the FWHM also decreases.



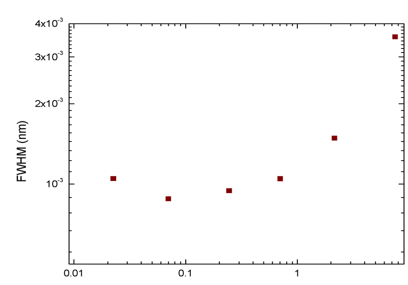
Power = 7.064 mW | Power = 2.043 mW | Power = 81.62 μW

As the scan rate is decreased from 200 V/s to 50 V/s, the FWHM of the broadened peak increases. Finally, microtoroids with a higher Q-factor tend to experience greater broadening than those with a lower Q-factor.



Scan Rate = 200 V/s | Scan Rate = 50 V/s | Q = 1.14×10^7 | Q = 1.83×10^6

Below is a graph of one of the early data sets for a microtoroid in air at a scan rate of 200 V/s. The plot indicates that the FWHM increases substantially after a threshold power of 500-600 microwatts is reached. After this point, any increase in input power causes an exponential increase in FWHM. More data was collected for powers before and after this approximate threshold point for subsequent data sets.



Future Work

Future work includes finishing data collection and data analysis. After, the results of the analysis will be interpreted and explained to quantify thermal broadening.

Acknowledgements

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